

Entered as matter of the second class at the New York, N. Y. Post Office, November 26th, 1890.

VOLUME XII. }
NUMBER 4. }

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Annual Subscription \$5.00

Single Copies - 50

APRIL, 1895.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.



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PUBLISHED MONTHLY BY THE INSTITUTE, UNDER THE
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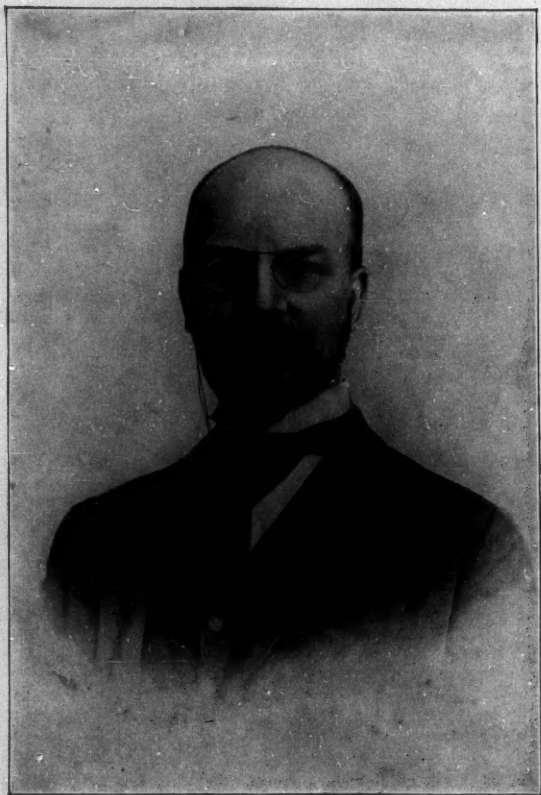
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RESONANCE IN ALTERNATING CURRENT LINES.

BY EDWIN J. HOUSTON AND A. E. KENNELLY.

In a paper, by one of the authors, on the subject of "Impedance," read before the INSTITUTE¹ on the 18th April, 1893, the drop of pressure in conductors carrying alternating currents and assumed to possess no capacity, was considered. In the present paper, it is proposed to consider the conditions of current and pressure in an alternating current circuit, possessing electrostatic capacity as well as inductance, resistance, and leakage.

The objects of the present paper are, therefore:

(1) To present the formula expressing the variation of electric current and pressure in an alternating current circuit under the most general conditions, and in its simplest form.

(2) To present calculations for the pressure and current in any alternating current circuit, by a graphical method.

(3) To investigate the effects of static capacity in an alternating current circuit.

(4) To investigate the effects of capacity and inductance on the delivery of energy at the distant end of a circuit.

In Fig. 1, let A B, be a length of $L = (L_1 + L_2)$ miles, or kilometres, of conducting circuit, supplied at A, with an E. M. F. of E volts, and connected to any desired apparatus at B. First assuming the line to be grounded at B, let e , be the pressure in volts, and i , the current strength in amperes entering the line at A. If the E. M. F. is alternating, the values of E and i , will be their effective values, such as are indicated by properly constructed voltmeters and ammeters. If the E. M. F. is continuous,

1. TRANSACTIONS, vol. x, p. 175.

the values of E and I , will be their ordinary numerical values. If the E. M. F. is alternating sinusoidally, E and I , will possess not only numerical magnitudes, but also direction in a plane. Let e , be the E. M. F. in volts, and i , the current strength in amperes at B , the receiving end of the line. When B , is grounded, we must have $e = 0$, and when B is insulated, $i = 0$. At any intermediate position C , in the line, distant L_1 , miles or kilometres from A , and $L_2 = L - L_1$ from B , let the E. M. F. be e , and the current strength i .

In any circuit, whether alternating or continuous, we assume that the pressure and current are known at one end of the line at least; that is to say, we know either E and I , or e and i . It is, therefore, required to determine e , and i , at all intermediate distances under the given conditions.

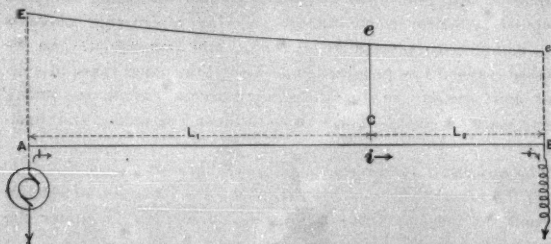


FIG. 1.

Under ordinary conditions we have to supply at the distant end of the circuit, a steady pressure of e volts, to a transformer, motor, or other translating device, and, when the load is known, i , is usually known.

In practice, lines are not usually grounded, a metallic circuit being employed. It is probably simpler, however, to discuss the phenomena as they occur on ground-return circuits, and then to bring metallic circuits within the treatment, by regarding them as composed of two parallel, grounded circuits, with the ground connection at the center of the generating E. M. F. at A , and at the center of the translating device at B . Each line will then have half the E. M. F. and half the impedance of the transmitter and receiver. (See Appendix III).

Regarding now the line AB , as being perfectly insulated be-

tween A and B , and as operated by a continuous E. M. F., we know that the pressure at any point is equal to the terminal pressure, with the addition or subtraction of the drop, according to the terminal considered, or

$$e = E - I L_1 r = e + i L_2 r \quad \text{volts} \quad (1)$$

and

$$i = I = i \quad \text{amperes} \quad (2)$$

where r , is the resistance of the conductor in ohms per mile or kilometre. The above simple relations between pressure, current, and distance, in a continuous current circuit, undergo comparatively simple variations in an alternating current circuit. Suppose an alternating E. M. F. E , of the sinusoidal type, and of angular velocity $\omega = 2\pi n$, n being the frequency, be employed on the line at A , with a current i , which may or may not be in phase with E . The line may possess an inductance of l henrys per mile or kilometre, a capacity of c farads per mile or kilometre, and a leakage conductance (the reciprocal of insulation) of g mhos per mile or kilometre. Then formula (1) becomes, in the case where all these quantities are present.

$$e = E \cosh L_1 z - I y \sinh L_1 z = e \cosh L_2 z + i y \sinh L_2 z. \quad (3)$$

$$i = I \cosh L_1 z - \frac{E}{y} \sinh L_1 z = i \cosh L_2 z + \frac{e}{y} \sinh L_2 z. \quad (4)$$

It will be seen that formula (3) differs from formula (1) in that the pressures E and e , are multiplied by the hyperbolic cosine of the quantity $L_1 z$, or $L_2 z$, according to the end of the line considered, while the current strengths I and i , are multiplied by the hyperbolic sines of the same quantity, and also by the quantity y .

In other words, the pressure at any point on the line, instead of being equal to the pressure at some other point of reference, plus or minus the drop between them, is equal to that reference pressure multiplied by the hyperbolic cosine of a function of the intervening distance, plus or minus a drop $I y \sinh L z$, which is also a function of the intervening distance, and these two quantities are not added numerically but geometrically.

Formula (4) is a more complex form of formula (2).

The quantities y and z , in formulas (3) and (4), depend on the impedances of the conductor and of the dielectric. The impedance of the conductor may be graphically represented as follows: Let the line r (Fig. 2), represent to scale, the resistance of the conductor per mile (or kilometre), and let $l \omega$, be the conductor

reactance per mile, or the product of the angular velocity of the E.M.F. and the inductance in henrys per mile. Then the vector sum will be $(r + j l \omega)$ where $j = \sqrt{-1}$, will be the conductor impedance, shown by the dotted line c. i., and hereafter contracted c. i., expressed in ohms per mile at the angle α .

The impedance per mile of the dielectric has next to be found. Here we have a capacity in parallel with a leakage. The joint admittance of these quantities will be the sum of their separate admittances $g + j c \omega$, Fig. 3. The length of the line g , representing the leakage conductance per mile in mhos, and $c \omega$, the dielectric-susceptance per mile, obtained by multiplying the capacity in farads per mile by the angular velocity ω . Then the line D. A. will

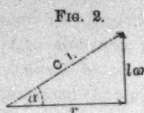


FIG. 2.

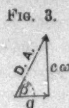


FIG. 3.

FIG. 4.

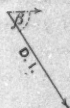


FIG. 5.

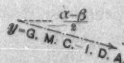


FIG. 6.

be the dielectric-admittance, hereafter contracted D. A., in mhos per mile, at the angle β . The dielectric-impedance D. i. will be the reciprocal of this admittance at the same angle $-\beta$, but negative, or below the line, as represented in Fig. 4.

The quantity z , is the geometric mean of the conductor impedance and the dielectric admittance, or

$z = \sqrt{C.I. \times D.A.}$, in the most general case a vector at an angle $\frac{\alpha + \beta}{2}$ as shown in Fig. 5. This quantity z , will hereafter

be described as the mean c. i. D. A.; i.e. the geometrical mean of the conductor-impedance and the dielectric-admittance.

$y = \sqrt{C.I. \times D.I.}$, in the most general case, a vector at an

angle $\frac{\alpha - \beta}{2}$, as shown in Fig. 6. This quantity y , will hereafter be described as the M. C. D. I. (geometrical mean of conductor and dielectric impedances). When the line is very long, the apparent resistance of the line from the sending end is y , so that the current strength entering the line will be $I = \frac{E}{y}$ amperes.

To illustrate, suppose a line whose conductor has a resistance of 2 ohms per mile, and an inductance of 20 millihenrys per mile, a perfect insulation ($g = 0$), and a capacity of half a microfarad per mile ($c = 0.5 \times 10^{-6}$). Let $\omega = 2000$, corresponding to a frequency $n = 318.3$ then,

$$l\omega = 0.020 \times 2000 = 40 \text{ ohms, and } c\omega = 10^{-3} = \frac{1}{1000} \text{ mho,}$$

then the conductor impedance, C. I. = 40.05 $\angle 87^\circ 08'$ ohms. The dielectric-admittance D. A. = $10^{-3} \angle 90^\circ$ mho. The dielectric-impedance D. I. = $1000 \angle 90^\circ$ ohms.

$$\text{Then } z = \text{M. C. I. D. A.} = \sqrt{0.04005 \angle 177^\circ 08'} = 0.2001 \angle 88^\circ 34'.$$

$$y = \text{M. C. D. I.} = \sqrt{40.05 \times 1000 \angle 2^\circ 52'} = 200.1 \angle 1^\circ 26' \text{ ohms.}$$

The quantities $L_1 z$ and $L_2 z$, are prolongations of z ; *i.e.*, vectors obtained by multiplying z , by L_1 and L_2 and setting off the product at the angle of z , in this case $88^\circ 34'$.

In order to determine e and t , we require to find the hyperbolic sine and cosine of the quantities $L_1 z$ and $L_2 z$. If $L_1 z$ and $L_2 z$, were mere numerical magnitudes, their hyperbolic sines and cosines could be determined from tables of those functions, but since $L_1 z$ and $L_2 z$, are vectors whose angle is $\frac{\alpha + \beta}{2}$, the hyper-

bolic sines and cosines are vectors and are tedious to compute. This labor can be avoided by the use of Plate I, which will give by inspection, the value of any hyperbolic sine and cosine within a certain range of magnitude, sufficient for most practical purposes.

When the plate is employed to determine hyperbolic cosines, it is held so that the letters R, appear in their correct position to the observer. To determine hyperbolic sines, the plate is held at right angles to this position.

If we have a point p , Fig. 7, situated in a plane, and we know its rectangular co-ordinates x and y , we may readily determine its polar co-ordinates r and θ , by calculation. Thus, if $x = 1$

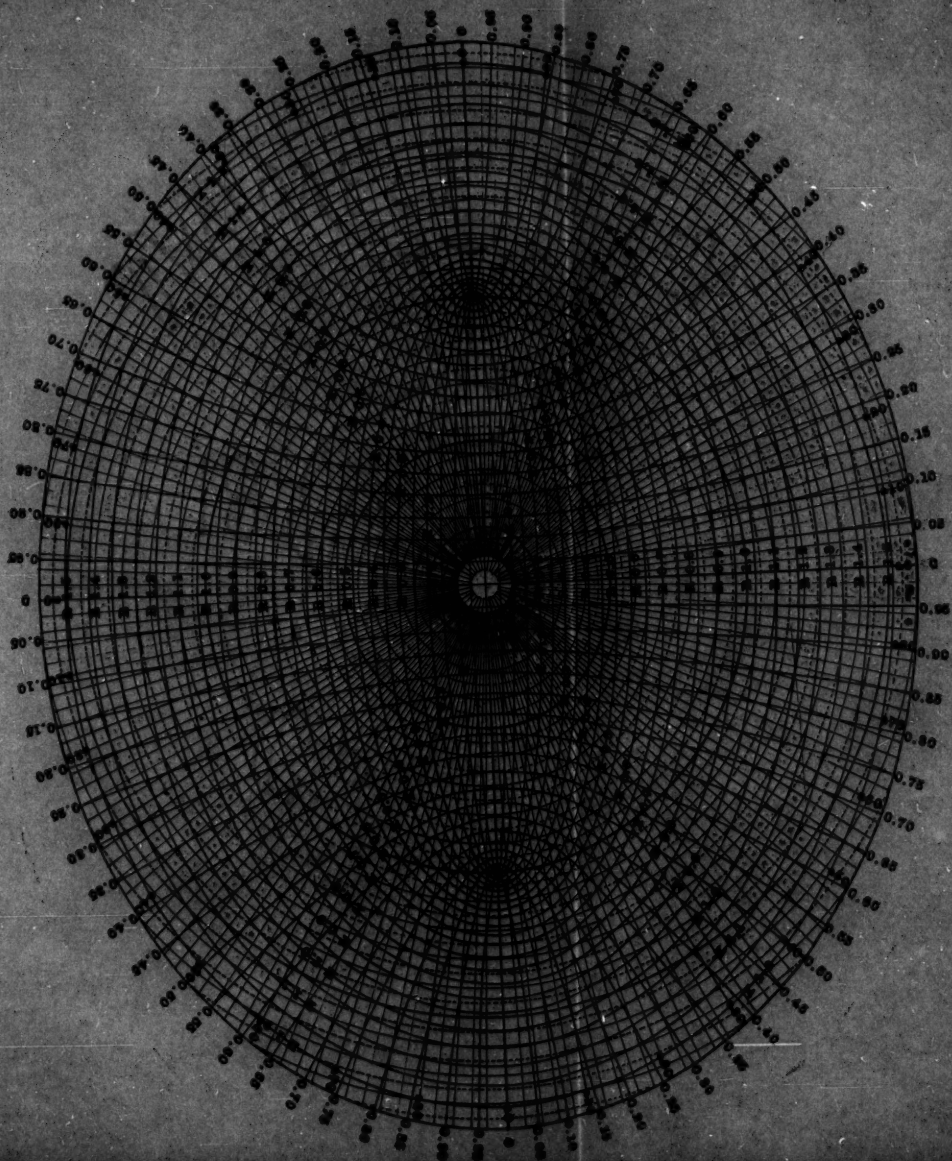
major axis of the ellipses at the right hand extremity, and counting γ , counter-clockwise, we find a hyperbola ERF , Fig. 7. This hyperbola is marked $\gamma = 0.7$. We then find the ellipse $x = 0.2$, ORD , and, at the intersection of these two lines will be the point whose polar co-ordinates give the hyperbolic cosine of the vector sought; namely $R = 0.5$, $/21^\circ 15'$, for R , lies on the circle of radius 0.5, at an angle, counted counter-clockwise from OD , of approximately $21^\circ 15'$.

Turning Plate I through 90° , and again starting in this position, from the horizontal line OO , or the line of minor axes of the ellipses, we enter the plate for the hyperbolic sines of the same vector whose co-ordinates are $x = 0.2$ and $\gamma = 0.7$. We travel counter-clockwise from the right over the same ellipse as previously employed, and, at its intersection R , Fig. 8, with the hyperbola ORD , of $\gamma = 0.7$, we have the point whose polar co-ordinates give the hyperbolic sine required. This point lies between the circles $R = 0.9$ and $R = 0.95$, but nearer to the former and approximately at a radius $R = 0.92$ and an angle of approximately $84^\circ 15'$.

It will be observed that the ellipses are carried by successive steps of 0.05, as far as $x = 1.25$, so that the diagram is limited in the range of abscissas to this amount. Since, however, counting counter-clockwise, γ passes from 0, at the right hand side to 1, at the vertical, 2 at the left hand side, 3 at the lower vertical, and 4 at the starting point on the right hand, and so on, 1 to every 90° , or 4 per revolution around the diagram, any value of γ , can be accommodated.

The diagram, therefore, becomes practically, to a moderate degree of approximation, a graphic table of hyperbolic sines and cosines of any vector quantity contained between the rectangular co-ordinates $x = 0$, $\gamma = 0$ and $x = 1.25$ $\gamma = \infty$. This range is sufficient for most problems that present themselves. Formulae for computing hyperbolic sines and cosines beyond this range are given in Appendix I.

In order, however, to obtain this extended range of γ , by repeating its value in successive cycles of 4, it has been necessary to alter the numerical values of the ordinates γ . Since the natural period of revolution is 2π , or 6.2832, corresponding to $\gamma = 4$ in the diagram, each unit ordinate of the diagram corresponds to $\frac{2\pi}{4}$ or 1.5708. In entering the plate, the ordinate of the vector $L_1 z$.



or $L_2 z$ must be reduced in the ratio of 1 : 1.5708 or be multiplied by 0.6366. Thus, if $L_1 z$ happens to be $1.118 / 79^\circ 42'$, we should find, as in Fig. 9, that $x = 0.2$ and $y = 1.1$. Multiplying y , by $\frac{2}{\pi}$ or 0.6366 we have (Fig. 9), $x = 0.7$ and the hyperbolic sine and cosine of $x = 0.2$ and $y = 0.7$ are already given in Figs. 7 and 8.

Plate II. affords a graphical means of accomplishing this reduction of the y co-ordinate by inspection. If, for example, we look for $y = 1.1$ along the axis of abscissas, we find $x = 0.7$ as the corresponding ordinate. So that having found the abscissa x and ordinate y , corresponding to a given vector Lz , we find from Plate II. x , the transformed value of y , and enter Plate I. with x and y .

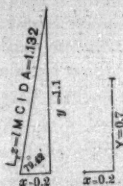


FIG. 9—Showing Analysis of Lz into Rectangular components to

$$Y = \frac{2y}{\pi}$$

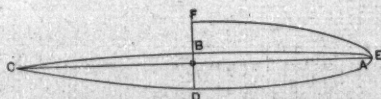
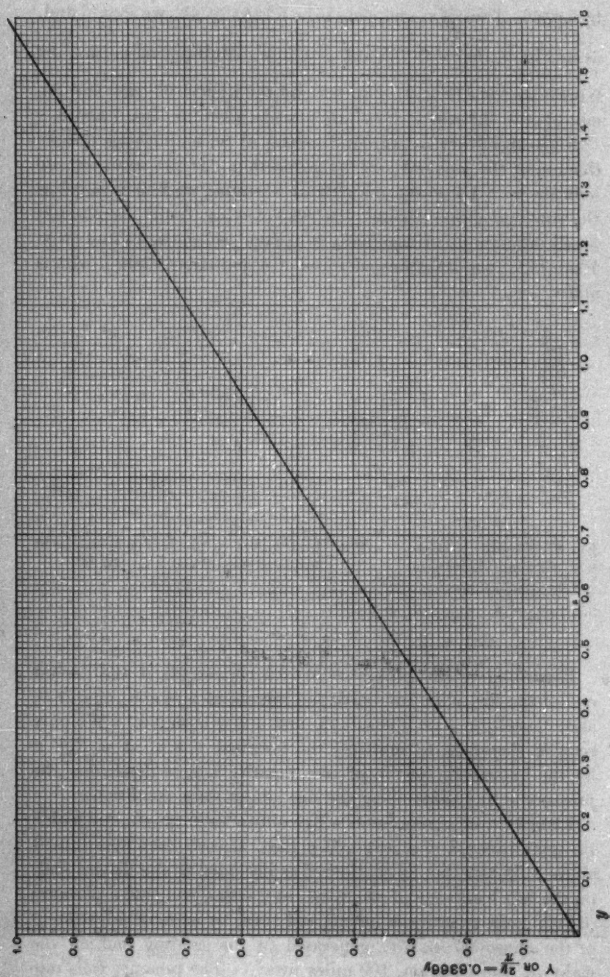


FIG. 10—Diagram of pressure commencing at insulated distant end $e = 1000 / 0^\circ$

Returning to the general equations (3) and (4), if the distant end of the line B, be insulated, the current at B, is zero, or $i = 0$, and, therefore, $e = e \cosh L_2 z$, and $E = e \cosh Lz$. We only require therefore, to multiply the terminal E.M.F. at B, Fig. 1, by the hyperbolic cosine of the quantity $L_2 z$, to determine the pressure at any point along the line under these conditions.

Plate III., at A, represents a line 100 miles in length, for which the quantities r , l , σ , g , ω , z and y , have already been determined above. If this line be considered as insulated at the distant end, on the left hand side of the plate, at 0 miles, and that a pressure of 1000 volts effective is maintained there by suitable adjustment of the sinusoidal E.M.F., generated at the sending end on the right of the diagram, 100 miles away. The pressure falls rap-

PLATE II. for transformation of y coordinates before entering Plate I.

idly along the line marked *volts*, until it reaches a minimum of about 50 volts, eight miles from the receiving end. That is to say, if the line were only eight miles long, and a sinusoidal generator, of angular velocity 2000 radians per second, were inserted at this point, it would only be necessary to maintain a pressure of about 50 volts effective at the generator terminals, in order to maintain the pressure of 1000 volts effective at the insulated receiving end. At a distance of about 16 miles from the receiving end, the pressure again rises to 1000 volts, and continues to rise and fall rhythmically in stationary waves, the length of which is approximately 16 miles. It will be observed that the amplitude of the waves diminishes toward the sending end, while the average value of the pressure increases, so that if the length of the line were made sufficiently great, the pressure would rise very considerably at the sending end, and the waves or fluctuations in the pressure would practically disappear. In other words, $\cosh L_2 z$, and $\sinh L_2 z$, approach more and more nearly circular paths, since the ellipses of z , show less and less ellipticity as their numerical value increases.

Similarly by formula (4), for an insulated line, i , being equal to 0, we have $e = \frac{e}{y} \sinh L_2 z$, and the curve of *amperes* at Δ .

Plate III, represents the corresponding series of currents for this line. This current commences at 0, at the receiving end, where the line is open, and in the next eight miles increases to five amperes, falling again in the next eight miles to about 0.5 ampere, the wave length of the stationary waves, being also approximately 16 miles, and the current strength increases, steadily rising towards the sending end, the amplitude of the fluctuations diminishing.

The maxima, or crests of the current waves, coincide with the minima, or troughs, of the pressure waves, and *vice versa*. Moreover, the pressure and current coincide in phase at each pair of maxima and minima, so that the phase of the current and pressure coincide four times in each wave length.

Following the line of volts from 0, at the receiving end of the line, and taking the pressure of 1,000 volts there received as the standard of phase, the pressure advances steadily in phase as we approach the sending end. At eight miles from the receiving end, the phase is 90° or a quarter cycle, in advance; at 16 miles 180° ; at 32 miles, 360° , or one complete cycle; at 96 miles, three

complete cycles. In other words, if we consider the pressure at the sending end (100 miles) as at standard phase, the pressure at the receiving end will lag more than three complete cycles. Similarly, the current along the line of amperes will at 0 mile be of strength 0, but $\frac{1}{4}$ cycle ahead of the pressure, and will steadily advance in phase towards the sending end, and at 100 miles the current will be nearly $3\frac{1}{4}$ cycles ahead of the current at the receiving end.

Fig. 10 represents the phase variation of the pressure in the first 40 miles; o A, represents 1,000 volts, the received pressure at the insulated distant end, at standard phase; o B, represents 50 volts $/90^\circ$, the pressure about eight miles along the line; o C, 1000 volts $/180^\circ$ or negative, the pressure at about 16 miles; o D, 150 volts $/270^\circ$ or $150 \backslash 90^\circ$ at about 24 miles; o E, 1,000 volts $/0^\circ$ at about 32 miles; o F, 220 volts $/90^\circ$, at about 40 miles.

From this diagram it is evident that a complete wave of pressure, having reference both to phase and amplitude, is about 32 miles in length, but in relation to amplitude only, is about 16 miles. Similar reasoning applies to the current strengths, and it is evident that at points along the line differing in distance by 16 miles, the current is in opposite directions at any and every instant.

Plate III, shows at B, the conditions of current and pressure existing along the line when the distant end is grounded at 0 miles, and a current of one ampere is caused to flow to ground. In this case the pressure is zero at the distant end, and formula (3) gives

$$e = i y \sinh L_2 z; i = i \cosh L_2 z, \text{ with } i = 1 / 0^\circ \text{ amperes.}$$

The curve *amperes* commences at 1, and at eight miles falls to about 0.05 ampere $/90^\circ$; the pressure at the same distance being about 200 volts $/90^\circ$, so that the pressure and current are in phase. They then fall out of phase, until at 16 miles, when they come into phase again at values

$$i = 1.0 / 180^\circ \text{ ampere approximately.}$$

$$e = 20 / 180^\circ \text{ volts approximately.}$$

The same general conditions are maintained throughout the line along the B, curves; namely, the pressure and current come into step every eight miles. The phase advances 90° for each eight miles toward the sending end. The wave length, in reference to amplitude alone, 16 miles, and in reference to both

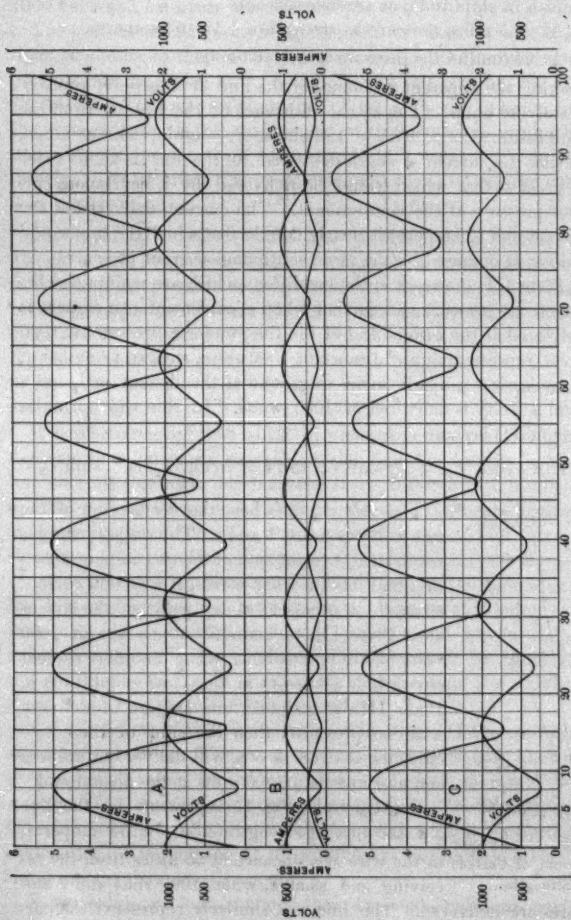


PLATE III.

amplitude and phase 32 miles. The pressure and current, on the average, rise towards the sending end, while the fluctuations diminish in amplitude, or are damped out.

At 94.5 miles the current strength is $1.12 / 60^\circ$ amperes.

At 94.5 miles the pressure is $100 / 0^\circ$ volts,

making the apparent resistance of the line at this point approximately 90 ohms. The actual resistance of the line is, from the data assumed, $2 \times 94.5 = 189$ ohms, or, roughly, twice as much, so that the current strength delivered to the line is about twice as great as that which would be delivered by a continuous-current pressure of the same amount. The current delivered at the distant end (1 ampere) is nearly double that which the line would deliver if operated by the same continuous current pressure.

Plate III, shows, at c, the conditions which are maintained between the pressure and current when a current of one ampere is delivered at the distant end of the line, under a pressure of 1000 volts, representing a resistance of 1000 ohms, such as a number of incandescent lamps in series to ground at the distant end, and a total activity is delivered of 1000 watts. In this case formulas (3) and (4) become

$$e = e \cosh L_2 z + i y \sinh L_2 z \text{ and } i = i \cosh L_2 z + \frac{e}{y} \sinh L_2 z.$$



FIG. 11. — Vector Sum of Current Strengths.

The *volt* curve is here the vector sum of the two volt curves in A and B. The *ampere* curve is similarly the vector sum of the two ampere curves in A and B. In other words, if a certain current strength is necessary at any point in the line as at A, Plate III, to maintain a pressure of 1000 volts, with no current, while another current strength is necessary at the same point, as at B, Plate III., to maintain one ampere of delivery with no pressure; then the sum of these two currents, at c, or $A + B$, will deliver one ampere and also maintain 1000 volts at the distant end.

For example, Fig. 11 represents by the line O A, the current strength ($3.35 / 79^\circ 30'$ amperes) sum of current in the wire at a distance of 35 miles from the receiving end, as at A, when 1000 volts and 0 amperes are delivered. The line A B, similarly represents the current strength ($0.79 / 8^\circ 10'$ amperes), in the wire as at B, when

0 volts and 1 ampere are delivered. The vector sum $o b$ ($3.70 / 68^\circ$ amperes, represents the current strength at this point when 1000 volts and 1 ampere are delivered, as at c .

The general conditions c , being the sum of those at a and b , must be similar to those already traced, namely, the current and pressure are in phase at 0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 79, 86 and 94 miles approximately. They both rise in value, on the average, towards the sending end, with fluctuations diminishing in amplitude, the phase advances by 90° , every eight miles (nearly). At 94 miles, the pressure is 1220 volts $/0^\circ$ and the current $3.6 / 0^\circ$ amperes.

The apparent resistance of the line at this point is, therefore, 339 ohms, and the activity $1220 \times 3.6 = 4392$ watts. The continuous-current pressure, which would have been required at this point, to supply one ampere at the distant end, would be 1188 volts, and the activity 1188 watts. We, therefore, require nearly four times as much activity in this line at a frequency of $318.3 \sim$ to yield the same power at 0 miles, as is required from a continuous source of E.M.F.

It is to be observed that while the pressure and current strength fluctuate in value as we pass along the line, the activity in the line does not fluctuate, but increases from 1000 watts at 0 miles, to 4392 watts at 94 miles. The rise is not uniform, being greater at the antinodes of current, or at the crests of the current waves, since the $i^2 r$ expenditure is greatest at those points; but the activity never ceases to rise as we advance toward the generator; for, it is evident that the activity in the line at any point, expressed by the co-directed product of pressure and current there existing, must, under the conditions here assumed, be equal to the terminal activity of 1000 watts, plus the total $i^2 r$ activity spent in the line up to the point considered.

The conditions of the line considered in Plate III. are not such as occur in practice. The frequency of $318.3 \sim$ is only known in telephony, being six or eight times as great as would be employed for long-distance power transmission. The capacity of 0.5 microfarad per mile would only be obtained in large buried cables, and the inductance of 20 millihenrys per mile is several times greater than usually occurs.

Nevertheless, we have assumed these extreme conditions, partly for the purpose of obtaining conditions favorable to the devel-

opment of resonance in the line, and partly to disprove the claim that has been made as to the economy offered by resonant lines for the transmission of power. It is evident that if a conductor, intentionally loaded with inductance and capacity so as to be resonant to the frequency employed, offered economical advantages for the transmission of power, there would, probably, be no great difficulty in artificially loading and adjusting the line resonance. For this reason the investigation of purely hypothetical conditions is not devoid of practical interest.

It is clear, from an examination of the conditions at B, as already described, that the resonance of the line enables a greater current strength to be supplied through the grounded distant end than would otherwise be possible. In other words, by heavily loading the line of 2 ohms per mile, with inductance and capacity until its inductance-reactance is 40 ohms per mile, and its capacity-reactance 1,000 ohms per mile, we can deliver, roughly, twice as much current to ground through the distant end, over any length between eight and 24 miles, as would be possible with an unloaded line. Under these circumstances, however, the current delivers no energy. In order that it may deliver energy, the pressure at the distant end must be raised. When this is done, as at C, the advantage, at first gained, by increasing the possible current strength, is soon more than lost by the additional expenditure of power in the line.

In any alternating-current circuit, if there is no loss of energy, by leakage and hysteresis, in the dielectric surrounding the conductor, that is to say, if the line is aerial, and is perfectly insulated, the activity delivered to the line at the sending end must be equal to the power delivered at the receiving end, plus that wasted in the line as $i^2 r$. Any method, therefore, of supplying a given number of volts and amperes at the distant end, which entails variation from the mean or average value of the current strength, *i.e.* any method which induces fluctuations in the current strength, must unduly increase the total expenditure of $i^2 r$, and entail either a greater loss in transmission, or a greater expenditure in copper, except where the current to be delivered is great, and its delivery pressure small, conditions opposed to long distance transmission. In the case represented at C, Plate III, the activity absorbed by the line is 4,392 watts at 94 miles, of which only 1,000 watts are delivered at the distant end, making a loss of 3,392 watts in the line, or an average loss of 36.1

watts per mile, due entirely to $i^2 r$, and such as would be produced by a steady current of 4.25 amperes, the actual current fluctuating between 1 and 5.95 amperes. Continuous-current transmission, or alternating-current transmission at a low frequency, over the unloaded line, would have supplied 1,000 watts at a steady current of 1 ampere, and with a loss of only 188 watts.

Were it possible to make an alternating-current transformer, or an alternating-current motor, resonant; *i.e.*, if it were possible to tune sympathetically into resonance, not only the line, but also the energy translating device at the distant end, it might be possible to derive an advantage from the use of a loaded circuit, in spite of its greater $i^2 r$ loss. But an examination of the conditions of resonance shows, that where resonance exists, very little work is being done. A highly resonant condenser has its pressure and current in quadrature, and, generally, the mere existence of resonance implies an elastic reflection of energy with the minimum absorption. In other words, the conditions requisite for the maximum delivery of work to such a device, are inconsistent with the conditions requisite for its resonance.

While, therefore, in the case of a telephone circuit, it is possible that the current strength through the distant telephone, may, at some particular frequency, or range of frequencies, be increased, by loading the line, since the amount of work done in a telephone is small, yet when power has to be transmitted over a circuit on a large scale, it is wasteful to load the circuit.

And now as to the conditions favorable to the existence of marked resonance in an alternating-current circuit. When an alternating *E. M. F.*, of E volts, is connected to a condenser through an inductant resistance of R ohms, the current strength in the circuit will attain the maximum value of $\frac{E}{R}$ amperes, when the inductance-reactance $l\omega$, is equal to the capacity-reactance $1/c\omega$. Similarly, a conducting line tends to vibrate electrically in sections such that their inductance-reactance and capacity-reactance are equal. The complete wave-length will be $2\pi \times$ the length of conductor in which these reactances are equal. With reference to amplitude only, the wave-length will be $\pi \times$ length of equal reactances, and the length in which the maximum amplitude of vibration is attained, $\frac{\pi}{2} \times$ length of equal reactances. For ex-

copper wires (diameter 0.325" or 0.825 cm.) supported on poles at an interaxial distance of two feet. The inductance of each wire in this metallic circuit will be 1.69 millihenrys per mile (3.38 millihenrys per double mile or loop-mile), and the capacity of each wire 0.0179 microfarad per mile (0.00895 microfarad per loop-mile). At the high commercial frequency of 133 $\sim$ or $\omega = 835.6$, the inductance-reactance will be 1.412 ohms per mile, and the capacity-reactance 66,840 ohms per mile. The length of line in which these two reactances would become equal is 217.6 miles, making the wave-length, in regard to amplitude, 683.6 miles, and in regard to both amplitude and phase, 1,367 miles. For this line z , the geometrical mean C. I. D. A., is 0.004745 $/79^\circ 53' 30''$, indicating by the preceding table, a maximum possible rise of nearly 270 per cent. If the loop were 336 miles long, the calculated rise in pressure is 250 per cent, with the distant end insulated, so that 1,000 volts at the generator would produce 3,500 volts between the insulated ends 336 miles away. In existing practice, however, a more reasonable length would be 10 miles, and over such a length, the rise of pressure would only be from 1,000 volts at the generator, to 1,001 volts at the insulated distant ends, a quite insignificant amount, and when even a small load is thrown on at the distant end, the drop in the line, due to that load, would neutralize and reverse this rise first produced.

With reference to subterranean conductors in practical use, the Ferranti mains may serve as an example. The particulars for these mains are given by Dr. Fleming in his interesting paper on "Some Effects of Alternating-Current Flow in Circuits having Capacity and Self-Induction," as follows: (see Appendix II) $r = 0.034$ ohm, $l = 0.2857$ millihenry, $c = 0.367$ microfarad, $n = 67 \sim$. The inductance-reactance is, therefore, 0.1203 ohms per mile, and the capacity-reactance, 6472 ohms per mile; so that the length in which these reactances are equal is 231.9 miles. The amplitude wave-length would, therefore, be nearly 729 miles.

Owing, however, to the very small inductance of this line the angle of the mean C. I. D. A. is only $55^\circ 53'$, representing only a small rise of pressure under the most favorable conditions, and over such a great length as 360 miles, the resistance of the conductor would practically damp out all resonance. In a length of 11.49 miles, the maximum length tested by Dr. Fleming, the rise of pressure at no load should be nearly 0.3 per cent., or near-

ly 30 volts in 10,000. Observations 13 and 14 of Table I., on p. 391 of his paper, show this rise, although other observations show a greater rise. The readings of the voltmeters are stated to have necessarily been subject to some little inaccuracy.

Formulas (3) and (4) are capable of including the effects of dielectric hysteresis when measurements of the same have been made; for, the effect of hysteresis in a dielectric, is to permit the expenditure of energy in it, as though leakage occurred across it, and the leakage conductor g , has only to be increased until $e^2 g$, is the total wasteful activity in watts in the dielectric per mile due to hysteresis and leakage combined.

The formulas are also applicable to triphase transmission when the proper inductance and capacity of the three conducting lines are employed. See Appendix III.

Formulas (3) and (4) are in the most general form and assume simpler forms in special cases. Thus if $l = 0$ and $c = 0$, we have the case of a leaky continuous-current circuit. In this case y and z , become numerical, instead of vector, quantities. Consequently $\sinh Lz$, and $\cosh Lz$, are numerical quantities, capable of being obtained from trigonometrical tables of these functions. The pressure in this case never rises towards the distant end of the line. When the distant end of the line is insulated, the pressure falls along a curve which is a simple catenary.

When $g = 0$ and $c = 0$, we have the case of an alternating-current circuit with negligible leakage and capacity. The formulas then become

$$(3) \quad e = E - I L_1 (r + j l \omega) = e + i L_2 (r + j l \omega).$$

$$(4) \quad i = I = i$$

Here $(r + j l \omega)$, is the impedance of the conductor per mile, and the current strength remains the same throughout the line. As an example, suppose that the line consists of a pair of No. 0 A. W. G. aerial wires, each one mile long, at an interaxial distance of 2 feet, the frequency being 140 $\sim$. If a transformer be supplied at the distant end, with a pressure of 2000 volts at standard phase, and a current strength of $50 \sqrt{10^9}$ amperes, required the pressure and current at the generator. The impedance factor for such a pair of wires is 3.08, and the angle whose secant is 3.08 is $71^\circ 3'$, so that the impedance per mile is $1.602 / 71^\circ 3'$ ohms. The pressure at the sending end on each line is, therefore, $1000 + 50 \sqrt{10^9} \times 1.602 / 71^\circ 3' = 1000 + 80.1 \sqrt{61^\circ 3'}$, and the vector sum of

these is $1041.5 / 3^\circ 52'$. The E.M.F., at general terminals will therefore be $2083 \text{ volts} / 3^\circ 52'$. The current at the generator is $50^\circ \sqrt{10^\circ}$ amperes.

Although, as we have seen, a sinusoidal E.M.F. at ordinary commercial frequencies, has very little power to produce resonant effects in ordinary transmission lines, yet, where prominent harmonics exist in the E.M.F. of the generator, we may expect, since the frequency of these harmonics is some odd multiple of the fundamental frequency, that they will be able to excite resonance when the fundamental practically fails to do so. It should be remembered, however, that in practice, the amplitude of the harmonics in an E.M.F. usually diminishes with the order, *i.e.*, the frequency of the harmonic, and, consequently, that although a high harmonic may be capable of developing powerful resonance in a line by reason of its frequency, yet by reason of its small initial amplitude the effect of such resonance on the total pressure will be necessarily reduced. It is possible, however, under special conditions, that an E.M.F., differing markedly from the sinusoidal type, may give rise to a considerable elevation in pressure at the distant end of a line, and this is an argument in favor of the sinusoidal type of E.M.F. wave in generators for long distance transmission.

We have not yet had the opportunity of verifying the rise in pressure, or resonant effects here described, in an actual alternating-current circuit. As already pointed out, a circuit in order to manifest such effects in marked degree should have considerable length, good insulation, low conductor resistance, large capacity, large inductance and a high frequency.

Through the courtesy of the Pennsylvania R. R. Co., through its Division Operator, Mr. W. F. Taylor, we were able to make some measurements of current strength and pressure over various lengths of telegraph circuits, both with continuous and alternating currents, employing with the latter a frequency of $125 \sim$. The resistance of a telegraph line is so large, relatively to its inductance and capacity, that at this frequency, the angle of the mean C. I. D. A. was only 54° , and, consequently, no marked resonant effects could be expected. There were, however, marked differences between the measurements with continuous and alternating currents. The results were in agreement with theory within the limits of uncertainty as to the magnitude of the inductance, capacity, and leakage of the lines.

The effect of inductance in an alternating-current circuit, possessing negligible capacity, is to increase the drop in the conducting lines, without sensibly increasing the energy expended in the lines by a given current strength. Consequently, for any given activity supplied at the receiving end, at a certain pressure and current, the pressure at the generating end is raised above that which would be needed if the circuit could be operated by continuous currents. There is, therefore, a certain percentage of increased capacity in the generating plant, *i. e.*, an increased pressure for the same current strength, and the cost of the generating plant, therefore, tends to increase, owing to the inductance in the line, although the expenditure of energy in the line is not sensibly increased. The effect of capacity in the circuit is opposite to that of inductance, the pressure tending to rise at light loads along the line under their combined influence. At the same time the current, which is employed in charging and discharging the line, expends some energy in the conductor as i^2r . The cost of the plant is, therefore, reduced, as the pressure at the generator is reduced, but more power is expended in the conductor. The benefit to be derived in this manner from capacity in the line is, however, limited. Beyond a certain capacity-reactance, the loss of power in the line, owing to its resonance, costs more than the saving in generator capacity.

We conclude, therefore, from the foregoing, that in an alternating-current circuit:

(1) The combined effect of capacity and inductance is to produce a tendency to resonance.

(2) The tendency to resonance is favored by high frequency, high insulation, high inductance, high capacity, and high conductance.

(3) When the line is free at the distant end, the resonant effects are more pronounced at that end than at the generator.

(4) The determining factor for the production of resonance is the angle of the vector geometric mean c. i. d. A., and rapidly increases with the same.

(5) The complete wave-length in a resonant line is 2π times the length, in which the reactances of the inductance and the capacity are equal, the maximum difference of pressure or current strength being exhibited in one-quarter of this wave-length.

(6) When resonance occurs, the current and pressure in the circuit are not in phase except at their maximum and minimum values, *i. e.*, at the crests and troughs of the waves.

(7) In resonant circuits, the lag of the pressure and current is 90° between any successive pair of maximum and minimum values.

(8) In ordinary lines, worked sinusoidally at ordinary frequencies, resonant effects are practically negligible.

(9) Prominent upper harmonics in the E. M. F. of the generator may sometimes give rise to appreciable resonant effects, although the resonance to the fundamental frequency may be inappreciable.

(10) A certain amount of capacity tends to increase the plant efficiency of the generator, and is, therefore, economical, but marked resonance in a line not only ceases to be economical, but is actually wasteful.

(11) Although, on a large scale, less energy can be delivered at the distant end of a powerfully resonant line, than on a non-resonant line, yet a greater current strength can in some cases be delivered over a powerfully resonant line.

APPENDIX I.

Useful Additional Formulas.

Vectorially, $\cosh(a + j b) = \cosh a \cos b + j \sinh a \sin b.$ (5)

" $\sinh(a + j b) = \sinh a \cos b + j \cosh a \sin b.$ (6)

Numerically, $\cosh(a + j b) = \sqrt{\cosh^2 a - \sin^2 b}.$ (7)

" $\sinh(a + j b) = \sqrt{\sinh^2 a - \sin^2 b}.$ (8)

The apparent resistance of a line $A B$, from the sending end A , when insulated at B , is $y \coth Lz$ ohms;

" grounded at B , is $y \tanh Lz$ ohms.

When L , is great, these converge towards y ohms.

The apparent resistance of a line $A B$, at the receiving end B , when grounded at B , and supplied with E. M. F. at A , is $y \sinh Lz$ ohms.

Example I. Required the hyperbolic cosine of the vector $1.118 / 79^\circ 42'$ whose rectangular co-ordinates are $x = 0.2$ and $y = 1.1$,

$$\begin{aligned} \text{by (5) } \cosh(0.2 + j 1.1) &= \cosh 0.2 \times \cos 1.1 + j \sinh 0.2 \times \sin 1.1. \\ &= 1.0201 \times 0.4536 + j 0.2013 \times 0.8912. \\ &= 0.4627 + j 0.1794. \\ &= 0.4963 / 21^\circ 12'. \end{aligned}$$

Example II. Required the hyperbolic sine of the same vector
by (6) $\sinh(0.2 + j 1.1) = \sinh 0.2 \times \cos 1.1 + j \cosh 0.2 \times \sin 1.1.$
 $= 0.2013 \times 0.4536 + j 1.0201 \times 0.8912.$
 $= 0.09130 + j 3.909.$
 $= 0.9136 / 84^\circ 16'.$

APPENDIX II.

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APPENDIX III.

I. In the case of a conducting line with ground-return circuit, r is the res. in ohms per mile or kilometre of the conductor;

l " ind. in henrys " " " "

c " cap. to ground in farads " " "

E " effective E. M. F. at A, Fig. 1;

e " " " B, Fig. 4.

II. In the case of a pair of conducting lines overhead, such as a uniphase arial metallic circuit, consider each line separately, as being supplied with an effective E. M. F., E equal to half the effective E. M. F. of the generator, and an effective E. M. F., e , equal to half the effective E. M. F. e of the motor, transformer or translating device.

r = res. in ohms per mile of one wire;

l = ind. in henrys " " "

c = twice the capacity in farads per mile as measured between the wires;

g = twice the conductance in mhos per mile measured between the wires.

When the conductors are buried, and each is surrounded with a metallic sheet, *e.g.* a lead covered cable, c , is the capacity in farads per mile of each conductor to ground, and g , the conductance (and hysteretic coefficient) in mhos per mile of each conductor to ground.

III. In the case of three triphase conductors, consider each line as a single conductor operated to ground by $\frac{1}{\sqrt{3}}rd$, of the effective E. M. F. measured between wires at each end, with inductance and capacity as modified by the presence of the two other active lines.

NOTICE.

Written discussions of the papers contained in this issue if acceptable, will be printed in the May number if received before May 1st.

The Secretary will esteem it a favor if his attention is called to any errors in either papers or discussion, in order that they may be corrected before printing the sheets for the annual volume.

The Institute as a body is not responsible either for the statements made, or for the opinions expressed, in the TRANSACTIONS.

[ADVANCE COPY—SUBJECT TO REVISION.]

UNDERWRITERS' RULES.

BY WILLIAM A. ANTHONY.

A recent controversy, in relation to inside wiring for incandescent lighting, has suggested to me the importance of bringing out a full and free expression upon the subject from those whose experience gives them the best right to speak, and I venture to bring the matter before the INSTITUTE in the hope that it may provoke such an expression as may have some influence in determining the character of any changes in the rules for construction that may be proposed, or in fixing the interpretation to the rules now in force. The present rules are, of course, the result of a process of evolution, and I think every one will admit that the process has been one of progress. In early days of electric lighting, the desire to conceal the wires led to fishing them in between floor and ceiling and between plastered walls, as had been done with electric bell and burglar alarm wires. Fires occurred, and were ascribed to the electric wires, sometimes rightfully, but no doubt sometimes wrongfully.

Insurance companies took up the matter, passed rules and appointed inspectors. Many of the rules were good, some were only an annoyance to the construction companies. Different boards adopted different rules, and often the inspector was a law unto himself.

Wishing to assist in securing uniformity, and feeling that electrical engineers, who have to do with the practical work of electrical installation, are best qualified to frame rules for electrical construction, the National Electric Light Association, in 1890, appointed a committee to take the matter in hand, and upon the report of this committee, in 1891, adopted a series of rules, which,

with some amendments adopted at later meetings, may be assumed to represent fairly well the consensus of opinions among the electrical fraternity, as to what constitutes a safe electrical installation.

Rules, substantially the same as those, have been adopted by the National Board, and various local boards of fire underwriters, and are the recognized rules in force at the present time.

The object of all rules is first, to secure a safe and permanent installation; second, to provide for the repair or renewal of conductors in case of failure. It may be said that from the standpoint of the insurance companies, the first is the only object, but surely, conductors so installed that they can be easily overhauled and replaced in case leakage is discovered, are safer for the very reason that a fault is likely to be repaired before any serious damage has occurred.

When highly insulated wires, whose insulation resistance was measured in megohms per mile after immersion in water for weeks, came into use for electric lighting plants, it was natural to suppose that they could be put anywhere, and would last indefinitely. They were put in all sorts of inaccessible places; on the beams before floors were laid, in partitions before plastering, on the lath with iron staples to be covered with mortar. Some such circuits are no doubt in existence to-day, as perfect in insulation as when first put up; but numberless cases of failures of insulation occurred, and experience shows that such a construction is entirely unreliable. Then came the interior conduit, which it was assumed would serve both as a mechanical protection and an insulator, but it was found not to be entirely reliable in either capacity. It was not impervious to moisture, it was subject to damage by nails, saws and chisels. It was found necessary to prescribe that wire of the highest insulation should be used in it, and that it should not be drawn in until all danger from mechanical injury was passed. Then came the brass armored conduit; but that was not nail proof. Now we have the iron armored conduit, and it remains to be seen whether this will fulfil all requirements.

It has come to be pretty well recognized that no mode of electrical construction is absolutely proof against failure at some point, and that form of construction is best which affords the smallest chance for injury or depreciation, and offers the greatest facilities for repair or renewal in case of failure.

There has been a uniform progress in the direction of greater

safety and better facilities for repair, from the time when wires were put anywhere, to be covered by floors, or mortar, or built into brick walls, to the iron armored conduit which is offered to-day. To be sure, the cost of the installation has advanced, and the iron armored conduit presents difficulties when alternating currents are employed. To me it seems that the advantages gained are worth the cost, and the difficulty with alternating currents disappears, if the two conductors are placed in one conduit. To this I can see no possible objection when the conduit is iron armored.

In view of the fact that we cannot be absolutely certain that failures in insulation will not occur in any given installation, it seems to me that the foundation principle of all rules for the placing of conductors should be accessibility. Further, no conductor should be placed where its position or its relation to other conductors in any part of its length is unknown. This means that raceways must be provided, into which conductors may be drawn and from which they may be removed at pleasure, such raceways to serve as adequate protection from mechanical injury; or the conductors must be placed in mouldings which are themselves accessible, or they must be supported by cleats or insulators in plain sight.

I believe that past experience would warrant the adoption of a rule that would require the use, for concealed work in buildings of fire-proof construction, where conductors must be carried up steel columns, over steel floor beams, in brick partitions, or in plastered walls, of a raceway or conduit, equal in its ability to afford mechanical protection to that known as iron armored conduit, so installed that conductors could be drawn in or out at any time.

And now a word as to the controversy that suggested this paper:

A conductor has been put upon the market, which consists of a standard Habirshaw wire with its covering of rubber and braid, having woven upon it two additional coverings of extra heavy braid. This additional covering, which is tightly woven on, and from which the wire can no more be removed than from its original covering of rubber and braid, the maker, by an extraordinary stretch of language, calls a tube, and claims for it the advantages of the conduit tube prescribed in the insurance rules. It goes without saying that this wire affords no means of re-

placing a damaged conductor, and, therefore, has not that advantage of the conduit. As to mechanical protection, it certainly is not superior to the unarmored conduit, and it has not the advantage that the conductor can be left out until the danger of injury is passed. As to insulation against moisture, the added coverings do not improve it, the insulation being entirely due to the rubber covering which is inside of all the braids.

And yet I have just learned that the New York Board of Fire Underwriters, on March 20th, passed the following resolution :

Resolved, "That the Superintendent be authorized, until further notice, to approve the use of the Attix tube and wire, when equal in quality and insulation to the samples submitted to this Board and tested, under the same conditions where tubing would be permitted ; provided that there is no splicing or tapping of the wire, but that its introduction shall be in all cases by the loop system ; that in new buildings, when necessary to carry it between floors and plastering, it shall be through holes bored in the beams, not less than two inches apart, a single conductor in each hole, out of the reach of nails ; and in old buildings, where necessary to carry it within the reach of nails, it shall be protected by some device from perforation ; and provided further that the wire and tube be carried intact into the cut-out boxes, and that in no case shall the outer covering be removed before introducing the core wire into the cut-out box."

It will be noticed that the wire is called a "tube and wire," when it is no more a tube and wire than the Habirshaw which forms its basis. The tests referred to, show that, after immersion in water or being imbedded in plaster, the insulation resistance was 20 megohms per mile. But the Habirshaw wire, without the Attix covering, would have shown the same. What then is the propriety of confining the operation of this resolution to the Attix wire? Why not permit the use of any good highly insulated wire under the same conditions?

It seems to me that this resolution is one of those reversions to an ancestral type which we find in all evolutionary development, which is off the general line of progress, and which is destined soon to become extinct.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 20, 1895,

The 95th meeting of the INSTITUTE was held this date at 12 West Thirty-first Street, and was called to order by President Houston, at 8.05 P.M. Eight-five members and guests were present.

The minutes of the meeting of February 27th were read by the Secretary and approved.

THE SECRETARY:—The following are the names of Associate Members elected, and transferred to full membership at the Council meeting, held March 20.

Name.	Address.	Endorsed by.
BOYLES, THOMAS D.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	C. P. Steinmetz. H. M. Hobart. H. G. Reist.
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Thorburn Reid. C. P. Steinmetz. H. M. Hobart.
DUNCAN, JOHN D. E.	81 Maplewood Avenue, Pittsfield, Mass.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
ESTY, WILLIAM	Instructor in Electrical Engineering, State University, Champaign, Ill.	C. R. Cross. Jas. B. Cahoon. D. W. Shea.
FROST, JOSEPH W.	Secretary, National Automatic Fire Alarm, 335 Broadway, New York City.	G. H. Stockbridge. Jos. Wetzler. R. W. Pope.
GARRELS, W. L.	Student, Westinghouse Electric and Mfg. Co.; residence, 4531 West Pine Boulevard, St. Louis, Mo.	Fred'k Bedell. Ernest Merritt. H. J. Ryan.
GILMORE, LUCIEN H.	Assistant in Physics, Stanford University, Palo Alto, Cal.	F. R. Medina. F. A. C. Perrine. Geo. P. Low.
GRIST, JAMES E.	Mechanical Engineer, Phila. Traction Co.; Residence, 918 North 44th St., Philadelphia, Pa.	H. S. Hering. F. Uhlenhaut, Jr. C. A. Bragg.
HISS, WM. J., JR.	Senior in Electrical Dept., Lehigh University; residence, 28 Market St., Bethlehem, Pa.	W. H. Powell. R. W. Pope. E. Caldwell.

JONES, HENRY C.	Member of firm, the Electric Construction and Supply Co., Montgomery, Ala.	A. E. Worswick. A. F. McKissick. C. H. Smith.
LARRABEE, ROLLEN N.	With the Western Electric Co.; residence, 30 W. 25th St., New York City.	H. F. Albright. G. A. Hamilton. E. S. Keefer.
MIDDLEMISS, P. R.	Post Graduate Student, Mech. and Elec. Engineering, Tulane University, New Orleans, La.; residence, 1616 Felicity St.	Brown Ayres. A. M. Schoen. R. W. Pope.
MORA, MARIANO L.	C. E., E. E., 63 West 70th St., New York City.	F. B. Crocker. Max Osterberg. W. H. Freedman.
MOSMAN, CHAS. T.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	C. P. Steinmetz. H. M. Hobart. H. G. Reist.
MERESHON, RALPH D.	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburgh, Pa.	C. A. Terry. H. A. Craigin. F. N. Waterman.
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co.; residence, 227 Mount St., Baltimore, Md.	E. J. Houston. A. E. Kennelly. Louis Duncan.
PATTON, PRICE I.	Sheble & Patton, Ltd., 1022 Arch St., residence, 3926 Walnut St., Philadelphia, Pa.	F. Sheble. Knowles Perot. C. M. Blanchard.
SHOCK, THOS. A. W.	Electrical Engineer, Electric Light and Power Co., Sacramento, Cal.	Geo. P. Low. F. F. Barbour. W. F. C. Hasson.
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 184 So. 3d St., Philadelphia, Pa.	A. E. Kennelly. E. J. Houston. W. C. L. Eglin.
STRATTON, ALEX.	With Crocker-Wheeler Electric Co., N. Y.; residence, 2013 5th Ave., New York City.	F. B. Crocker. Max Osterberg. W. H. Freedman.
Total, 20.		

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, December 17, 1894.

POWELL, WILLIAM HENRY	Electrician, Mather Electric Co., Manchester, Conn.
KIMBALL, ALONZO S.	Professor of Physics and Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.
MIX, EDGAR WOODS	Electrician, Thomson-Houston International Electric Co., Paris, France.
Total, 3.	

At the same meeting the returns from the nomination sheets sent in by the various members were canvassed by the Council, and the following ticket was prepared, to be known as the Council ticket, as provided by the Rules:—

For President, Dr. Louis Duncan of Baltimore.
 For Vice-Presidents, Dr. M. I. Pupin of New York City, W. F. C. Hasson of San Francisco, A. S. Hibbard of Chicago.
 For Managers, Carl Hering of Philadelphia, Bion J. Arnold of Chicago, Charles F. Scott of Pittsburgh, Dr. Cary T. Hutchinson of New York City.
 For Treasurer, George M. Phelps of New York City.

The regular ballot sheet will be sent out by the Secretary, as required by the Rules before the 15th of April, and, as usual, will contain, in addition to the Council ticket, the names submitted by the members for the various offices. This, of course, enables every member to vote for any candidate he may select, under what is known as the Australian system.

THE PRESIDENT:—If there is no other business which the meeting wishes to take up now, we will proceed to the regular business. I take pleasure in introducing Prof. Harris J. Ryan, who will read a paper on "A Method of Preventing Armature Reaction."

PROF. RYAN:—By way of introduction, I wish to call your attention to certain points in connection with orthodox practice, in the design, construction, and operation of direct current dynamo electric machinery. In the first place, you all remember that it is necessary, in order that a proper commutation fringe at all working load outputs be maintained, that a proper reluctance of the air-gap be used in machinery usually designed for incandescent lighting, or for purposes where the load output fluctuates seldom and very slowly, so that the attendant can be depended upon for the gradual shifting of the brushes as the neutral point changes. Here smooth bodied armatures are used, and the length of the air-gap is so adjusted that it is necessary to place as initial ampere-turns—for producing that flux through the armature which is necessary for the normal pressure to be developed by the armature, that number of ampere-turns that shall be greater at all times than the ampere-turns on the armature at any particular load. Now, that did very well, when one followed out that rule for the construction of machinery that should operate in practice for incandescent lighting, with success and with smoothness as to commutation, ease in the commutation fringe, and in general behavior. But later on was developed, of course, on account of the demand for railway power supply, a generator that would supply a power load that would fluctuate very much through very wide ranges, in very short amounts of time; and you could not depend at all on an attendant to be present to shift the brushes into an easy and proper position of commutation, and it was necessary to so design this machine that sparkless commutation, so far as possible, at any rate, can be obtained at all load outputs without shifting of the brushes. Without the carbon brush, this could never have been accomplished. With metallic brushes it makes no difference even if one does adhere to the rule of maintaining an excitation from pole-face to pole-face, a magnetomotive force that will always be ahead of the armature ampere-turns, and even if one does maintain a positive fringe for commutation of a considerable value, you would have sparking with metallic brushes at no load, if you had no sparking at full load, or the reverse of this. The carbon brush was applied with very material success, and if Mr. Steinmetz, at the Philadelphia meeting, had had a little more time probably he would have called

your attention to its use in commutation, in addition to the very interesting remarks that he made on the beneficial results that are obtained by maintaining a positive fringe by the use of saturated lugs in the ironclad armature. In the first place, it will be remembered from the discussion in connection with one of the papers at the Philadelphia meeting, that Mr. Steinmetz called the attention of the members present to the fact that if you use saturated lugs, normally saturated lugs, in an ironclad armature, you might then use a comparatively small air-gap and that the lugs would not allow, (when you applied series ampere-turns) the induction to be increased by the application of those series ampere-turns, which you know are necessary in order that a fringe shall be maintained positive. Series ampere-turns, if we have small initial ampere-turns—that is by initial ampere-turns I mean those ampere-turns that will bring the induction up to the normal at no load—and they are always small, of course, if we have a small air-gap; now if we apply series ampere-turns on the field in proportion to the load, we can very easily adjust those series ampere-turns so that the magneto-motive force from pole-face to pole-face will be ahead of the armature ampere-turns at all times. But we have to contend with this troublesome feature that is introduced, if we do not design the machine to guard against it: that the induction will come up with the application of such series ampere-turns which you remember are applied for the purpose of maintaining a positive fringe under the leading pole corner, so as to have the machine commutate as well as possible, at least under the load, without bad effects at the brushes. Now it was explained at that time by Mr. Steinmetz that if one saturates these lugs, (see Fig. 24 as used at board), that you would in that way keep the induction from being increased under the trailing pole corners, while you might allow it to be diminished a little bit under the advanced pole corners, and the relations adjusted in such a respect that you could add on series ampere-turns in this way with this small air-gap in such amount that the impressed ampere-turns under the leading pole corners at all loads would be ahead of the armature ampere-turns. In that way you would have a positive fringe and no danger, even on very heavy overloads, of having it come to zero or reverse with corresponding disruptive effects, which always occur at the brushes. With metallic brushes, even under those circumstances we should have a very bad behavior, and it is in connection with the points involved in the use of carbon brushes that I now want to engage your attention. If you can keep up the fringe then, (or the induction under the leading pole corners) to a considerable extent, a very fair fraction of the normal induction throughout a large portion of the range of load, unless there are too many ampere-turns on the armature, you can depend on the resistance of a carbon brush for reversing the current. First of all you can push a carbon brush over into the

neighborhood of a pretty large portion of the commutative fringe, or the induction in the leading pole corner, and on account of its resistance, not have much current circulate in the coils passing the point of commutation. And then again when the current comes up under load, and pressure is needed to reverse the current on account of the self-induction of this section, as a bar is passing out from under a carbon brush the section in contact with the carbon brush, with the bar having the current in the right direction coming from this side, (indicating with the use of Fig. 24,) with the conductors moving in that direction, that section grows smaller and smaller every instant, and finally is nothing as it passes out from under; that current density eventually goes very high. The current has not yet been reversed in the neighboring coil. It must be reversed, however, com-

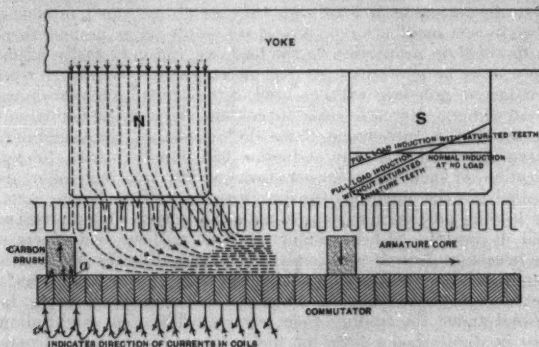


FIG. 24. (On blackboard.)

pletely, and brought up to the full value of the normal before it passes out, if any disruptive effect is to not occur. Now as this goes on, a very considerable local fall of potential occurs there (at A, in Fig. 24) and diverts a very appreciable amount of the pressure of the armature against the current that is in this coil in the former direction that it had on this side of the brush, and in that way the current is made to reverse through the action of the resistance of the carbon, and is the great reason why the carbon brush works with such wonderful smoothness on the old smooth-bodied armature where there is very little self-induction in the sections, and works with greater smoothness by far than any special metallic brush you could apply with the power generators, with the ironclad armatures, for the substantial mounting of conductors.

And then, while we are at this point in connection with ortho-

dox practice, it seems to me that the tendency at the present day is so far as possible to do away with those T-shaped teeth. That increases the self-induction of the section to a very considerable extent. Now these teeth are made in that shape for two purposes, one is to prevent the fluctuation of the induction density in the pole-piece, and that of course must be prevented when the pole-piece is not laminated; and the other is, that by using the T shaped lug you are able to mount in a very mechanical and workmanlike manner the conductors on the armature. But a part of these teeth can be made T-shaped, and the balance straight, and in that way the self-induction of the section is reduced very materially over the present practice, or rather the practice, at any rate, that has been in vogue within the last two years. You find the makers nowadays in many instances resorting to the use of a field core, made up entirely of laminated iron, or pole-pieces of laminated iron; or again, with these solid pole-pieces, straight lugs are used in recent designs, and the air-gap distance so adjusted that the Foucault current effects, the eddies developed in this pole-face, are such that desirable results are obtained.

Now I have called your attention to the fact that in all of this orthodox practice, the practice by means of which definite and the best results are obtained to-day, it is necessary to use the field ampere-turns somewhere, that will be ahead in magneto-motive force impressed between the pole-faces ahead of the armature ampere-turns at any load, if best results are to be obtained. And in the paper we shall look into the use of coils that will annul the effect of the conductors along the surface, and will see how, when that is done, the ampere-turns that are applied on the field, are only those that are necessary to set up the induction regardless entirely of any of these commutative requirements. In other words, one has the same magnetic conditions to look out for in estimating the excitation forces, as you have in an alternator that is free from self-induction in its own armature circuit, and is working on a non-inductive load. You are quite free from armature reaction effects, and a very small excitation suffices. These pernicious cross-leakage effects that occur with the use of deep grooves and saturated lugs under the trailing pole corner (indicated in Fig. 24) are quite obviated, so that woven or sectioned conductors are not necessary. The output of machines, all-told, has been increased through the application of such considerations very materially.

(Prof. Ryan then read the paper. See page 157, March issue.)

DISCUSSION.

THE PRESIDENT: This valuable and interesting paper is now open for discussion.

MR. TOWNSEND WOLCOIT:—It is interesting to notice the evolution of the dynamo, the differentiation of species, you may say. Those of us who have been in business for a number of years remember when dynamos were nearly all of one class, or at least there was very little difference between the different classes of dynamos. At first we had the old series machine. The first departure from that was the shunt machine, then the compound. Then we had the perfect regulation with the constant potential dynamo, then for a long time it was supposed that we could not have a constant current machine which gave perfect regulation without a regulating mechanism of some kind. Just about this particular time a machine of the opposite kind from the one we have just been hearing about is brought into public notice. That is a machine where the armature reaction is carried to the greatest extent for the purpose of regulation. That is the new Brush machine which has been developed by Mr. Black. In Prof. Ryan's machine which we have just been hearing about, the armature reaction is absolutely prevented. On the other hand, in the arc machine, the armature reaction is exalted to a very great degree for the purpose of getting the other kind of regulation. The desirability of entirely suppressing the armature reaction, perhaps, could not be questioned for a constant potential machine if it did not require the use of extra wire, etc. Perhaps it will be used as it is, but I think a great many dynamo designers are very certain that they can use the armature reaction to advantage even in shunt machines. For instance, it has been the hobby of some dynamo designers for some time, that shunt motors can be made to work satisfactorily, and regulated by means of the armature reaction, just as well as the compound motor with the shunt in opposition to the series coil, and, as a matter of fact, there are a great many shunt and compound machines, as at present built, which are not troubled with sparking.

MR. W. L. BLISS:—The paper read by Professor Ryan this evening is certainly very interesting, and of considerable value and I, for one, wish to thank him for it. I had the pleasure of being one of Professor Ryan's students at the time when he built his first machines with reactive or balancing coils, and under his direction made a number of experiments upon the same, which in all respects of operation, concur with what he has presented this evening.¹ In this manner I became quite familiar with the subject of armature reaction. But since I have gone out from under his care and guidance, I have been rather inclined to go astray in the matter of balancing armature reaction. It

1. *Sibley Journal of Engineering*, December, 1892; *Electrical World*, January, 7, '93.

seems to me that there must be some commercial impediment that precludes a more universal adoption of the methods outlined tonight. In the first place it is either on account of the additional cost of preparing these devices, and applying them to machines, or secondly the additional output does not warrant such expenditure, or lastly, if we do use these devices we are almost certain to interfere with some one's patent. It is the object of the manufacturer to patent as many useful inventions as he can for himself, and to dodge as far as possible, those of other people. We know that these schemes for balancing armature reaction are all bound up in the Patent Office, and consequently we can hardly censure manufacturers for not having utilized them. Their failure to use them is probably not a lack of knowledge upon the subject, but on account of commercial considerations.

To take up the various points in order:—Professor Ryan says that the poles have to be made particularly heavy for this kind of construction; and as we notice from the cuts of the machines he has presented, the poles are brought very close together. It seems to me that making the poles so exceedingly heavy adds weight and expense. Increasing the proximity of the poles must cause a considerable increase in the magnetic leakage which has to be made up by extra copper placed upon the fields and extra energy expended therein, while cutting holes through the faces of the poles seems to me to have a sort of throttling action on the field flux and reduces the useful cross-section of said poles that might otherwise be utilized to advantage. However, we are told that by filling up these holes or slots with the proper windings, and allowing the total current to circulate through them, we can overcome our armature reaction. The truth of this statement is borne out fully by experiment. We are also told that the clearance in large machines may be reduced enormously by the aid of such windings. I think, though, it is evident to nearly every one who sees large machines in operation, that a great deal of clearance is necessary, particularly in direct coupled machinery, on account of the excessive wobbling of the armatures. This clearance is far beyond that which would be necessary if the machine could be run perfectly steady and true, without the danger of a mishap to such a complicated and somewhat delicate structure as an armature. This air-gap may be nearly or quite sufficient to cause sparkless running, so why go to farther complication? These points should all be considered in estimating the value and advisability of adopting devices for balancing armature reactance.

I have here a few notes made in reference to the output of a machine, in watts per pound. Prof. Ryan states that the output of a machine can be brought up to a very high figure, and that the watts per pound of material can be made as great as 20 or 30. He speaks here about a machine that was designed for two kilowatts, and weighed 400 pounds, and had a peripheral velocity of 3,000 feet. This is only 5 watts per pound. We built at our

factory, some time ago a motor designed to operate a launch. It was of the 4-pole salient consequent type, completely iron-clad, and could be placed under water with impunity. The total weight was 185 pounds, and the maximum capacity 3.8 kilowatts, which you see was 20.3 pounds per watt. This machine operated with an armature 6 inches in diameter by 4 inches long, which you see is quite small, and yet the number of watts per pound was 20.3. This machine had a peripheral velocity of only 1,500 feet per minute and operated with a commutator of 45 sections, on which were set two brushes. The maximum current taken out of the commutator was 85 amperes, through a carbon brush about $\frac{3}{4}$ of an inch thick, and 2 inches wide. The motor ran in both directions on account of the service it was placed in, and could be operated under full load one way, or full load the other way without any shifting of the brushes. There was absolutely no sparking at the brushes. The brush-holders were bolted rigidly to the casing and there was no possible chance to shift them.

To illustrate further a case in which the armature reaction was not at all injurious, I will mention that for the last year or so I have designed machinery for car lighting purposes where the dynamo was driven by an axle connection. Here the object in view was to maintain the pressure practically constant on the lamps and on the storage batteries, at the same time utilizing a speed in the dynamo that varied from the time at which the dynamo was made operative, to the time at which the train was at the maximum speed, from 600 R. P. M. to 1,500 R. P. M., the latter figure representing a velocity of the train of about 60 miles per hour. Here we used a differential coil on the field magnets, through which the main current circulated, and which demagnetized the fields of the machine as the current and speed increased. And yet with these machines, using armatures 6 inches in diameter, by 6 inches long, which is exactly the same size as given in Prof. Ryan's paper, we were able to load down the machines to over 2 kilowatts, demagnetize the fields fully one half, and still they were sparkless, had fixed brushes and ran in both directions, which was evidently necessary on account of the service. We were able to accomplish these results without the use of balancing coils. When we first went into this extremely exacting work, we seriously contemplated using some armature reactive device, but we found we did not need it. It was at this time that we looked up the patent records and secured so much valuable information on this subject.

MR. E. A. MERRILL:—I would like to suggest that there are one or two points, which if covered, would make the paper a little more complete. You can take a high resistance brush and place it on the commutator in a position where the field is stronger than is required to reverse the current, yet without sparking; so if you had a dynamo which would give 115 volts

with the brushes correctly placed, the brushes might be so placed as to give an effective voltage of only 110 without sparking, so that 5 volts is wasted; this is corrected by the balancing coil.

There are some interesting curves here. Take the curve on page 164. I think it would have been instructive if Prof. Ryan had added curves, showing the effect of the balancing coils with decreasing field excitation, the maximum voltage decreasing in proportion, for with this coil you can get almost down to zero volts, certainly down to five or six, with curves exactly similar to the exploration curve on page 164, but diminishing in maximum height. This method gives a full control of the voltage and the output from the maximum voltage to the minimum without distortion of the field.

Then it seems to me it is a little unfortunate that curves 11, 12, 13 and 14 follow each other as they do. Fig 11 shows the dynamo without balancing coil and Fig. 12 the dynamo with balancing coil. It might be assumed from one following the

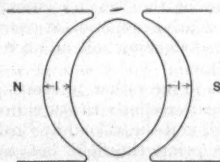


FIG. 25.

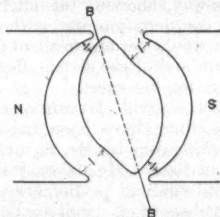


FIG. 26.

other, that the magnetization curve in Fig 12, was the necessary result of the use of the balancing coil. As a matter of fact, it is not the necessary result, and you would not get that curve if the balancing coil were designed to give the curve shown on page 164. The magnetization curve in Fig. 12 simply illustrates the fact that you have complete control of the distribution of magnetization in the pole-face and that you can take a pole-face with a weak pole, say at the top, and a strong pole at the bottom and reverse it; but if the same number of ampere-turns had been used in the balancing coil as in the armature, it would have given a uniform induction through the armature, and the same is true of the two curves, 13 and 14.

Then, if I could use the blackboard a moment, there is another method of plotting the magnetization, which makes it a little more graphic, and that is to plot the relative induction through the armature on radial lines, the depth from the pole-face to the curve representing the relative induction through the armature at all points. For example Fig. 25, shows for every

point in the pole-face very graphically the relative induction, and by plotting it for different field excitations and armature currents it shows the distortion produced by the armature current and also very plainly the effect of the balancing coil; the distance r from the curve to the pole-face on radial lines showing the relative induction through the armature. This figure shows the induction at no load, and is practically uniform over most of the pole-face, diminishing to zero midway between the poles. If a strong current is passed through the armature, the curve may assume the form shown in Fig. 26. The induction at r , as you see, is very slight and in fact may be reversed under certain conditions. The induction at r^1 is very strong, showing that these pole-tips are saturated. Now, if in addition to that, you indicate the position of the brushes and line of commutation at b , it shows graphically the strength of the field in which the commutation and reversal occurs, and it also shows on which side of the zero point it occurs, showing whether the voltage tends to be increased or diminished. Now, if curves were drawn in this way, showing the effect of the balancing coil, and also of the commutation lug, with the position of the brushes shown, you would get an excellent idea of the relative induction at every point, and of the actual effect which the balancing coil and commutation lug exert.

DR. CARY T. HUTCHINSON:—It seems to me rather interesting that there have been two attempts made recently to get rid of sparking, one by Mr. Sayer, of England, and the second by Prof. Ryan here. Mr. Sayer, instead of doctoring the field, puts an extra winding on the armature connected between the commutator bars of the coil to be short-circuited. This was found to work only in one direction. So recently he made an addition by putting on a commutating lug—a sort of postscript. Prof. Ryan starts with a balancing coil, and finds it does pretty well. But it does not answer under all circumstances. So he too adds an additional commutating lug. It is rather amusing to see that both should follow the same line. The first ideas are more or less ineffective; then they are improved to meet the conditions. I think that both of them are fundamentally wrong. There are so very many interesting points in a paper like this, that it is impossible to touch upon them all in an evening's discussion. But one thing in particular, I think, should be emphasized strongly. The fact that the output of any armature properly designed does not depend on sparking. Sparking is evidence of bad design, and should condemn the machine without regard to any other consideration. Any one taking this view will see at once that no device of this kind can increase the output of the machine in the slightest degree. It decreases the output of the machine for the reason that the extra winding takes up space that would be valuable. It adds weight; it adds copper. I hold the point of view that any machine, properly designed, will not

spark; and as a sort of comparison with this machine, I wish to give some figures of a machine which is in use in the city here, of the very simplest design, that does not spark under any conditions, short of the abnormal. It has no Sayer device and no balancing coils. It impresses me that the use of a balancing device is as if a man, wishing to walk along on a level, should walk up hill 150 feet and then down again. The armature effect takes you down, and the balancing coil brings you up. The machine described on page 174 is the largest mentioned, and it makes a fairer comparison than the others with the one I am about to describe. That machine may be taken normally to be 12 kilowatts. It has a total weight of 865 pounds. Leaving off the last item and adding the other weights, you will find that the "active" weight is, say, 740 pounds. The machine runs at a peripheral speed of a little over 2,800 feet a minute. Making this 3,000 feet for the purpose of comparison would mean an output of 17 watts per pound of active weight, with, of course, the balancing coils. There is pretty nearly as much copper in the balancing coils as there is in the main field coils. The machine I have in mind is of the ordinary Continental type, with two field coils, two salient poles and two consequent. It is a 30 kilowatts. Its total weight is 3,300 pounds, and its "active" weight is 2,600 pounds. It runs at a peripheral speed of only 1,500 feet per minute. Calculation will show that its output for that active weight is about 12 watts, roughly, at 1,500 feet per minute. Doubling that would give an output at a peripheral speed of 3,000 of, say, 24 watts per pound active weight. It is a plain ordinary machine, nothing special about it, and will carry 60 to 70 per cent. over load without a sign of sparking, without showing whether the current is on or off. Should we, however, make the comparison on a slightly different basis, referring still to page 174, it shows even more strongly in favor of the point I am making. You will notice that the watts lost in the armature proper in this machine are given at 618. The proportions of the two machines are very nearly the same, one, 10×5 , the other 18×10 . Assume that the radiation in my armature is the same as in the armature described here, and that, therefore, my armature could carry a current determined only by this heating; this would give 200 amperes, which it has carried without sparking. The output of the machine then would be 38 watts per pound active weight at 3,000 feet per minute. It seems to me that it is unnecessary to use the methods described here; that it is going back to archaic ages; for, in my opinion, any machine that needs this doctoring is fundamentally wrong. I believe a machine, instead of being designed with weak field excitation and low induction, should be designed on opposite lines, with strong excitation and heavy induction. One might think this would increase the weight of the copper in the fields and bring up the total cost of the machine. As a matter of fact, I find that the

weight of the copper, with the balancing coils, in the machine described on page 174 is 12.8 per cent. of what I call the "active" weight. In the machine I speak of, the proportion of field copper is only 10.1 per cent. It is an ingenious exercise, and not much more. Referring in the same way to another point, that the gap induction should be as low as possible, I take the opposite view, that it should be as high as possible.

There are quite a number of other points that one might bring up for discussion, but I will not take more time.

MR. CHAS. S. BRADLEY:—I am quite interested to know that there are machines which do not spark. I have heard of those before. Generally, however, I have found that they existed in the ideal of the manufacturer. Almost every man declares when he has constructed a new machine that there is no sparking whatever. But just as soon as anybody undertakes to use it, and the commutators get the least rough then they begin to spark, and I never saw one yet that did not spark, although I would go a good many miles to see one.

DR. HUTCHINSON:—Will you come up and see me to-morrow?

MR. BRADLEY:—I will be very glad to. I would walk ten miles to see one that did not spark.

DR. HUTCHINSON:—Come to the Postal Telegraph Company's building, 253 Broadway.

MR. BRADLEY:—Do you take care of it all the time?

DR. HUTCHINSON:—No, I never see it.

MR. C. O. MAILLOUX:—The paper read by Prof. Ryan is one which has undoubted merit in the beauty of its theory and the perfection of its experimental demonstration of the principle involved, whatever may be the commercial practical value of the invention. The point which was made by the preceding speaker is well taken in one sense, in regard to the heating limit, and it would apply particularly to this machine, because the ventilating space around the armature is so much reduced. There is little chance for convection or the motion of air currents by means of which heat can be dissipated. I have found that to be a strong objection, and one which has a direct influence on the heating limit of the machines. In fact, insufficient air circulation is more apt to reduce the capacity, in consequence of the heat limit being sooner reached, than is any excess of heating caused in the pole-pieces themselves by the eddy currents due to variations of magnetic density by the action of the teeth of the armature. In other words, the loss in dynamos caused by the eddy currents and the consequent heating in the machine frame, etc., is not as serious as is the reduction of the output capacity of the machine in consequence of its not being able to ventilate itself properly. One may, therefore, have a machine which, so far as the copper is concerned, would be very far removed from its possible capacity limit, whereas its practical capacity limit is sooner reached, due to the fact that it cannot dissipate the watts generated in the armature or pole-pieces.

One of the most interesting points, in my opinion, which Prof. Ryan has called to our attention this evening, and one which must interest a large number of those present, is the question of density in the armature teeth, and the density in the air-gap itself. There are many here who cannot afford to throw away the designs and patterns they have for manufacturing, the dies for punching the armature disks, etc., and they cannot quickly or readily depart from existing commercial and well-developed or well-established as well as successful types; yet, within certain lines they are very eager to develop their machines without introducing any radical changes; and it is to them that the question appeals with especial importance. Prof. Ryan called attention to the fact, which is now recognized, that we can palliate the difficulties of armature reaction by increasing the magnetic density of the armature teeth. I mentioned before this INSTITUTE, some two years ago or more, that in my practice I had sometimes carried the density of lines of force in armature teeth to such a degree that the permeability came down to something like two or three. About two years ago I had occasion to have a special motor made, and my attention was called by the party who was furnishing me the disks, to the fact that the total equivalent sectional area of the teeth was rather small in comparison with the sectional area of the armature itself, or the available iron for the passage of lines of force in the teeth was a very small proportion compared with the sectional area through the armature core itself. He was somewhat surprised when I told him this was done on purpose. I explained to him that I believed in having the magnetic reluctance entirely in the air-gap. It did not make any difference whether we had it in air or in iron, provided it was there; though there are certain evident advantages in having it in iron as much as possible. I had observed that by using high saturation of the armature teeth and high field density in the air-gap, it was possible to eliminate or palliate the difficulties resulting from armature reaction to a great extent, and consequently the machine became more sparkless, and had a higher load limit. In making the teeth narrower or deeper to increase the magnetic density, we gain incidentally, in the space available for wire, and thus increase the capacity of the machine. This plan has its disadvantages and limitations, I will admit. But it seems to me to be a point of great interest and, on which there must be many persons here who have experience.

Another point which I would like to have some of the gentlemen here discuss, is the question of magnetic density in the air-gap per square centimetre. My own experience indicates that practically there is no limit to the air-gap density; it is merely a question of what one is willing to pay for it in the form of watts wasted in producing the magnetizing current. The higher the density in the air-gap, the greater the extent to which one is enabled to reduce the armature reaction and increase the output

of the machine by making its load limit farther removed. With higher air-gap densities the air or extra-dental portion of the gap can be decreased without detriment. When I speak of the air-gap, I often include the total space between the face of the pole-piece and the bottom of the root of the tooth, or the inter-dental space. This does not seem as strange as it might at first seem, when you consider that in working at very high densities the permeability is approaching a value which is nearly that of air. In some calculations for special work, I have found myself obliged to take into consideration the joint reluctance of teeth and air space. Usually where such low densities are considered in the iron of the teeth, the number of lines of force—the number of square centimetres in the air of the air-gap between the armature teeth, (the inter-dental space) is of no consequence. But when you reach permeabilities as low as two and three, or even before that, the air itself between the armature teeth becomes a magnetic conductive medium of some importance. For that reason, it is perhaps quite as logical to treat the air-gap as if it were all air, with a portion of it more or less short-circuited, or having its magnetic reluctance enhanced by the presence of metal of higher magnetic conductivity.

The question is, I think, one of greater importance than might at first seem, and it has a great bearing on the question of good performance of machines and their output limit, consequently on their weight. I think it would be of interest to have the experience on that subject of many others here present.

DR. CHARLES E. EMERY:—I have made a large number of experiments on the general subject of armature reaction, and have seen the electromotive force reversed in a half cycle even worse than shown in the paper, where the polar surfaces of the field magnet were too large for the exciting force employed. With larger exciting forces the reversal did not take place. Referring to the proposed shifting of the brushes in lieu of compounding with coils, I frequently have been annoyed at seeing the tenders of the old bi-polar dynamos continually shift the brushes to try and reduce trifling sparks, with the result that the attendant on the switchboard platform had to make corresponding changes of his field regulators. In this connection I finally made a fairly elaborate series of experiments with modified windings designed to produce a neutral arc through which the brushes could be shifted for the purpose of compounding exactly as proposed in the paper. The sparkless arc was not successfully obtained, though the results were encouraging. About this time I had an opportunity to shift the brushes on one of the new General Electric generators when well loaded, and found that very considerable changes in the voltage could be obtained by shifting the brushes without producing sparking. It appears therefore, that dynamos are now so well designed that additional features would ordinarily not be warranted. If, however, the

improved details now proposed, greatly increase the capacity, this will furnish the desirable commercial feature to enable one bidder to guarantee a given overload at a lower price than another.

In any event, Prof. Ryan, not neglecting the co-author, again deserves our thanks for a record of careful experiments, revealing the underlying principles of interesting and important phenomena, and it will be pleasing if the devices designed to overcome well-known difficulties prove of considerable commercial value.

MR. A. E. KENNELLY:—The question at issue in this case seems to be not the question of the number of watts which can be obtained per pound of material, or, at least, that is not the primary and essential question. The primary and essential question in an engineering matter must be, what is the number of watts of output that can be permanently sustained per dollar of investment in the machine, and per dollar of up-keep and yearly maintenance, including depreciation and repairs. We all know that dynamos and motors spark. It is always a question whether the output of a dynamo or a motor is reached in its heating before it is reached in its sparking, and one of the two conditions must supervene to limit the output of the machine. In the modern practice it is the heating which limits the output, and not the sparking. But that does not altogether settle the question, because if it can be shown that by differences in construction, or in superiority of methods of ventilation, the heating temperature of elevation can be reduced, to enable the machine to be carried forward to a greater limit of output, so as to bring the question of sparking under consideration, then there is room for any device which checks and prevents sparking. The question can only be decided it seems to me, by actual experiments, and by actual estimates based on such experiments. The only guide we have in the paper before us as to the actual results possible, is in the statement that 20 to 30 watts per pound of total dynamo weight can be obtained by the method in use, and, as a rule, whatever exceptional dynamos may do, that is a greater output than standard machines to-day possess. I think the figures given for this machine described in the paper do not show anything like such an output, so that I think the figures are based on estimates, and not based on actual experience. Many attempts, as we all know, as the patent records show, have been made to overcome armature reaction, very frequently by adding lugs over the point of commutation in the armature. But I do not remember seeing any method quite so radical as this, which consists in providing two armature windings, one of which is intended to rotate, and the other to remain fixed.

Turning to the purely technical side of the subject, an interesting question appears to arise. We know that when a smooth-core armature is employed in a dynamo-electric machine, say a motor, the force which propels the motor when the electric current is

supplied to the armature, *i.e.* the electrodynamic force, is exerted on the substance of the conducting wires, and if they are not firmly secured to the armature body, they are liable to be forced or sheared electro-dynamically over the armature surfaces. The only function of the armature core, from a magnetic point of view, is to reduce the reluctance of the magnetic circuit through the armature, and increase the intensity of the magnetic field which reacts upon the active conductors.

When, however, the armature is tooth-cored, and the same conductors lie deeply imbedded in the iron surface of the armature, it is, I think, the general belief that, since the conductors lie in a space comparatively unoccupied by flux from the field magnets—since the flux passes [through the core of the armature without penetrating the substance of the conductors—that the current passing through these conductors magnetizes the iron of the core, and converts it, so to speak, into an electromagnet whose poles are attracted by the poles of the field magnet. In fact, it is sometimes claimed that the use of tooth-cored armatures not only prevents eddy currents from being developed in the armature conductors, but also removes from them the driving force, to the greater mechanical safety of their insulating coating.

In the experiments described in this paper, however, and as shown in Fig. 1, on page 158, the balancing coils, having a M. M. F., equal and opposite to that of the armature winding, must completely or nearly neutralize the magnetic influence of the armature winding upon the armature core, so that the iron of the armature does not become magnetized, like an electromagnet, by the action of the armature current. This is further evidenced by the series of observations presented in Figs. 10 and 17, in which it appears that the distribution of the flux over the surface of the active armature, is sensibly the same as when the armature remains inactive. From this it would appear that if the armature winding were mechanically free from the iron core in which it lies imbedded, it would rotate, or tend to rotate, with the full torque of the machine, leaving the core at rest within; also that the balancing coils attached to the field poles tend to rotate about the axis of the armature in the opposite direction. If this reasoning be correct, it would seem necessary to suppose that in this, and, therefore, in any tooth-cored armature, the electro-dynamic force is exerted upon the substance of the conductor and not upon the substance of the iron core, and I would like to ask Professor Ryan for the opinion he has formed upon this question from his study of the phenomena.

MR. GANO S. DUNN:—With regard to the high densities in the teeth, I would call attention to the fact that such densities are necessary only when we depend on shifting our brushes to stop the sparking. But if in a machine of small size, we do not depend on such means, but depend entirely upon the resistance of the carbon brush to reverse the coil, then a high density in the

teeth is a positive disadvantage, since it makes us have so much more magneto-motive force, or copper in our field coils. In a small machine the field energy is a much larger proportion of the input than in a large machine, which makes this an important point: for by letting the density in the teeth remain low we save just so much of what is already a large loss.

MR. C. O. MAILLOUX:—I would like to state in reply to the remarks made by Mr. Dunn that that statement does not necessarily always apply. I have found, in connection with the very machine which I refer to, which was run in both directions as a motor, that in spite of the very high density, with the set position of the brushes, there was no sparking, although the field excitation was not excessive. I think those things are largely a question of design. The design in this case was a four-pole machine of the consequent-pole type, similar to that which Dr. Hutchinson has described, and that may account in some manner for its wonderful performance.

With reference to the method of balancing devised by Prof. Ryan I do not quite agree with my colleague and friend, Mr. Kennelly, that it must be regarded as a stationary armature. I regard it rather, as strictly speaking, a system or set of compounding coils. I do not think we can regard it in any other way. And I think they are an ideal form of compounding from a theoretical standpoint. If we stop to consider compounding, we find that it means, substantially, to add enough extra coils so as to get an increased magneto-motive force sufficient to stiffen the lines of force and make them pass through their path, or to put it differently to overcome the added reluctance due to their distortion. Prof. Ryan finds that it is simpler to straighten them. He applies the force at right angles and merely restores the bent lines of force back to their position. I think if we investigate the forces in action, the final result is just the same as if we had a magnetic force acting at right angles with that of the field itself—or, strictly speaking, as Prof. Ryan puts it, in opposition to that of the armature. The armature tends to distort the field lines of force at right angles. It is a force acting tangentially to the armature; it bends the lines of force out of their course; Prof. Ryan simply bends them back. That, I think, is the ideal method because it always requires less force to produce the result, same as in mechanics, it is often simpler to use guys, and struts, instead of attempting to make the beam itself stronger and stiffer by increasing its size.

MR. MAXWELL M. MAYER:—I should like to ask the previous speaker, that, in case the density of the teeth is exceedingly high, so that the permeability of same is equal to the air, how the quantity of wire and the necessary energy wasted in fields, can be such a small amount as he has mentioned.

MR. MAILLOUX:—I must correct the gentleman. I did not state that. The permeability is something like 25. I was refer-

ring to other cases, such as street car motors, where it is not so much a question of saving copper as it is a question of space, and of the equally important matters of proper working under extraordinary conditions. I have not the figures in my mind of the machine I just mentioned, but, if I recollect rightly, the maximum permeability at the time of starting was something like 20.

MR. MAYER:—I should again like to ask Mr. Mailloux, or any of the gentlemen present, whether they consider using the teeth at very high inductions, and overcoming the armature reactions, more advantageous than using a low density, and decreasing the reluctance of air space to a minimum.

MR. MAILLOUX:—As I stated previously, I endeavored to have as much as possible of the reluctance in the air-gap. Of course, it goes without saying that the designer should always bear in mind the specific purpose for which the machine is intended, and that he should govern himself accordingly. What may be excellent for one case may be very bad in another case. I cannot answer the question of this gentleman because it would involve the analysis of a great many points, some of which are rather abstruse, while others would require access to comparative data.

THE PRESIDENT:—If there are no other remarks, I will call on Prof. Ryan to close the discussion.

PROF. RYAN:—I have been very much interested in the discussion myself. I have hardly anything to say, I think, in conclusion—possible one or two words.

I think Dr. Hutchinson was of the opinion that we advocated in our paper the lowest possible densities. Well, I meant by that, when you use the balancing coils, that of course then you do not need to resort to the very high induction densities in the lugs, in order to be able to add on series ampere-turns, without running up the induction and electromotive force of the machine. That is what we meant to refer to—what we had in mind when we wrote what we did.

With regard to the point mentioned by Mr. Kennelly, as to whether magnetic forces are brought to bear on the armature conductors when pole-face coils balance the armature reactive effects, or whether they are still on the armature lugs, I would explain what my own view is in connection with that matter, because it seems to me that this is a subject of a good deal of practical importance. If the forces, through balancing the reactive effect, are thereby made to be exerted on the conductors, then of course, one is reverted to a set of mechanical features which are not so desirable. It seems to me, however, that this force, even if one has balanced the effects entirely so that at all outputs of the armature the field is uniform for the pole-face and throughout the air-gap, that the forces are still a kind of drag on the armature core and not on the armature conductors, and the reason why I think so is this: It seems to me that the electro-

motive forces that we get there are produced rather by the including and the excluding of induction in one direction, and then in the other direction through the armature coils as is the case in the transformer. The forces at work on the coils there are those more especially due to the proximity of two coils with currents in opposite directions. We all understand, I think, that great variation of induction occurs at high rates, and large electromotive forces are produced that set up no forces between the primary coil and the iron circuit. You may have such transformer coils carrying heavy currents at considerable pressures, representing large powers, and yet we ordinarily experience no mechanical action of the iron circuit on these coils. I see no reason why similar results may not be obtained in a dynamo. This is the view I have had of the matter, and I think it is an interesting point brought up in the manner in which Mr. Kennelly has presented it.

DR. HUTCHINSON:—I do not see how the attraction can be on the teeth, as Mr. Kennelly suggests, for the reason that the magnetization of the teeth does not increase in proportion to the current in the armature, and the torque does. Therefore the pull must be on the conductor carrying the current.

[Adjourned.]

ANNUAL AND GENERAL MEETINGS.

The Annual Meeting for the election of officers, the presentation of yearly reports, and the transaction of other business will be held at 12 West 31st Street, on Tuesday, May 14th, 1895, as provided by the Rules.

The General Meeting for the reading and discussion of papers, will be held at Niagara Falls, beginning on June 18th, 1895, the date fixed by Council. The manuscripts of papers intended for this meeting should be placed in the hands of the Secretary by May 1st, in accordance with the requirements of the Committee.

Members desiring to present papers, who have not already done so, should communicate with Mr. T. C. Martin, Chairman of the Sub-Committee on Papers and Meetings, or the Secretary.

Further particulars of the above meetings will be given later.

OBITUARY.

GEORGE MAY PHELPS, who has faithfully served the INSTITUTE as Treasurer since his first election to that important office on May 17, 1887, died of pneumonia at his residence in Brooklyn, N. Y., on April 11th, 1895, after an illness of but five days.

Mr. Phelps was the only son of the late George May Phelps, Sr., and was born at Troy, N. Y., in 1843. He was educated in the public schools and high school of that city. Since 1861, he had been continuously engaged in electrical interests, excepting for an interval of five years. He was first employed in the shop of the American Telegraph Company, of which his father was superintendent. He afterwards served in the Auditing Department of the American Telegraph Company from 1863 to 1866. From 1871 till 1879 he was assistant to his father in the management of the factory of the Western Union Telegraph Company in New York City. In April, 1879, the Western Union Company disposed of its manufacturing interest to the Western Electric Company, and Mr. Phelps was appointed superintendent of the factory by the latter organization, which position he held until December, 1885. In August, 1886, he joined Mr. Franklin Leonard Pope in conducting *The Electrician and Electrical Engineer*, at that time published monthly, acquiring a proprietary interest in that journal shortly after. The title of the journal was subsequently changed to *The Electrical Engineer*, and, beginning April 2d, 1890, it was issued weekly, the business being incorporated under the same title, with Mr. Phelps as President.

Mr. Phelps was a charter member of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, and was elected one of its managers on May 19th, 1885. He served on the Council in this capacity until his election as Treasurer, on May 17th, 1887, to which office he has been re-elected each year, and which he held at the time of his decease. He had been nominated for the same office by the Council for the term beginning May 14th, 1895. He had also served on various standing and special committees, and has at all times readily given his time and services to the interests of the society.

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